Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
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Mississippi Agricultural and Forestry Experiment Station

## CONTENTS



## ILLUSTRATIONS



## TABLES

# ꜰFECTS OF REPETITIVE COMPRESSION ON LINT-COTTON PACKAGING

By W. Stanley Anthony[1]

## ABSTRACT

Experiments were conducted to determine the effects of repetitive ɔression on lint cotton as a means of improving the appearance of ɔotton bale and producing a satisfactory bale package. A small-scale press was used in repetitively compressing lint cotton to constant ity and constant pressure. In compressive-force tests the cotton was under compression for 10, 30, or 50 seconds, released 12 inches, and recompressed. The bales were immediately recompressed five times, the maximum force required to attain a maximum density of ap- imately 40 lb/ft$^3$ was measured. Resilient force exerted by bales being compressed one or six times was monitored at densities of :0, and 35 lb/ft$^3$. In another compressive-force test bales were com- ɜed, the ram lowered, and the bales recompressed. The procedure repeated 11 times with constant maximum pressure. Then the bales compressed at 1,800 lb/in$^2$ to a platen separation of approximately :hes, and the ram was lowered slowly to a separation of 12 inches. bales were then recompressed at the same pressure, and force versus .ty was monitored as the ram descended. Repetitive compression ɜed the force required to compress the lint cotton as well as the re- ıt force exerted by the cotton. The results of these experiments ate that repetitive compression can reduce bale-tie breaka; by enhance the shape and appearance of cotton bales. **KEYW ressive and resilient forces, constant density and pressure, lir itive compression, small-scale bale press.**

## ʼRODUCTION

; of lint cotton into bales re- ntion from producers, ginners, rnmental agencies, trade as- ndustry. The final appearance ɜnces its marketing and usage uate packaging techniques and bale-tie breakage, which de- appearance, quality, and net value. Since the adoption of the universal density bale, most emphasis has centered around a packaged bale density of 28 pounds per cubic foot (lb/ft$^3$).

Broken ties alter the bale's uniform shape. The nonuniform bale is subjected to abusive handling, since it will no longer fit into the normal-sized storage area. Broken ties on the end of the bale produce a flared effect commonly referred to as a fan-headed bale. The fan-headed bale is difficult to handle, and foreign material is readily absorbed by the flared section. Lack of dimensional uniformity in the

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bale prevents bale-covering material from adequately protecting the bale.

Two factors that enter into the engineering aspects of packaging lint cotton are (1) the force required to compress lint cotton, and (2) the force required to restrain lint cotton (resilient force).[2] Reduction of these forces could improve the bale package by reducing bale-tie breakage. Numerous methods and equipment to reduce compressive and resilient forces have been suggested and evaluated. One method of reducing these forces, repetitive compression, has received considerable attention.

Repetitive compression must be considered from two standpoints, constant density and constant pressure. The constant-density approach simply means that the bale is repetitively compressed to the same density. From a practical standpoint, the constant-density approach can be accomplished by presses equipped with microswitches that stop the ram at the same point for every press cycle; many automatic presses are so equipped. The constant-pressure approach is utilized by some press systems in which the ram stops when the predetermined pressure is reached during each press cycle. In both systems the final packaged bale density (density-restrained-at) must be 28.0 lb/ft$^3$, or higher, since 28.0 lb/ft$^3$ is required to classify the bale as universal density.

The objective of this research was to test the following hypotheses:

1. Repetitively compressing lint cotton to the same final density requires less compressive force for the recompressive cycles and causes less resilient force to be exerted by lint cotton.

2. Repetitively compressing lint cotton with the same maximum pressure increases the final-density-pressed-to (lb/ft$^3$) and reduces the resilient force exerted by the lint cotton.

In both cases, the effect of less resilient force would suggest a reduction in bale-tie breakage.

[2] Anthony, W. S., and McCaskill, O. L. Forces involved in packaging lint cotton. The Cotton Gin and Oil Mill Press, July 21, 1973, 74(15):7–11.

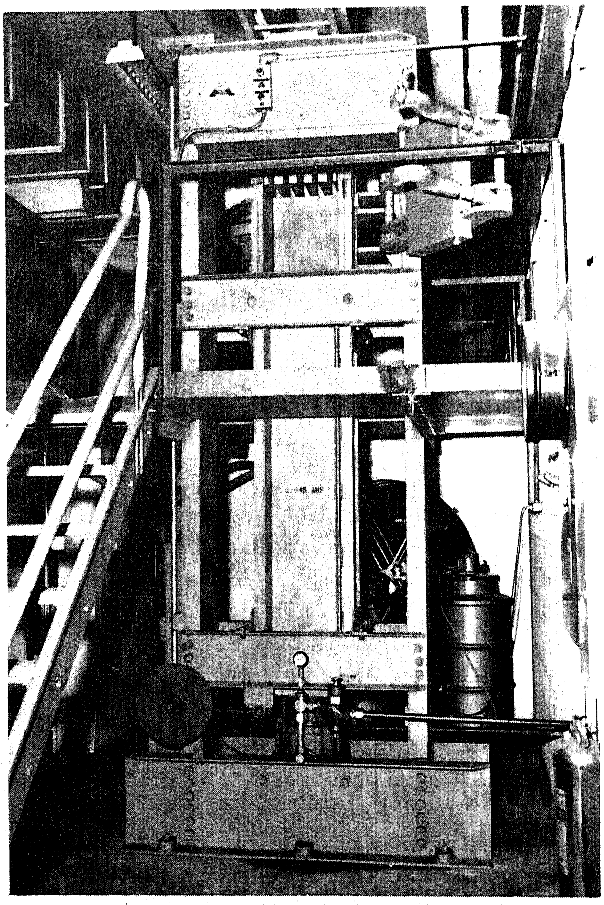


FIGURE 1.—Small-scale bale press used in study.

## EXPERIMENTAL DESIGN, METHODS, AND MATERIALS

The research was performed in two major experiments—repetitively compressing lint cotton to constant density and repetitively compressing the cotton to constant pressure. Each of the two experiments was divided into two tests, one to evaluate compressive force and the other to evaluate resilient force. The constant-density experiment required 18 bales of cotton, and the constant-pressure experiment, 9 bales.

A small-scale bale press with a cross-sectional area of 1 ft$^2$ was used instead of the larger industrial press (7.5 to 9.0 ft$^2$). The small-scale press reduced the lint-cotton requirement from 13,500 to 540 lb. However, the end results are qualitative, and caution must be exercised in predicting quantitative results on full-scale systems.

Seed cotton was processed through the cleaning machinery in a full-sized ginning system and weighed and stored; then it was condi-

tioned in a small-scale ginning system[3] for 48 hours at 75° F and 55% relative humidity. The same climatic conditions were maintained during the tests. The seed cotton was then ginned and processed through one lint cleaner in the small-scale system. The lint was fed into the small-scale press through a lint slide and hand-packed to a density of 3.0 lb/ft$^3$ (fig. 1).

A dual-channel analog recorder was used to monitor the millivolt signal from a 100,000-pound-capacity transducer mounted above the top platen. The transducer output was calibrated to read directly in pounds. Force was measured as it was transmitted through the cotton. The surface of both slotted platens was covered with a ½-inch steel plate to allow measurement of all the force transmitted through the cotton. One channel and one event pen on the recorder monitored the output of two microswitches. The microswitches completed and opened the electrical circuit from the power supply to the recorder each one-eighth and each one-half inch of ram travel. A No. 40 roller chain attached to the bottom of the lower platen powered two sprockets that activated and deactivated the microswitches. The location of the lower platen was used to calculate press volume and thereby density. Thus, the force versus density relationship was monitored indirectly by the recorder.

Experiment 1 (constant density-pressed-to) was designed as follows:

Test 1A (compressive force):
1. Number of times compressed: 1 or 2.
2. Density-pressed-to: 20, 25, 30, or 35 lb/ft$^3$.
3. Compression rate: 5.06, 2.70, or 1.80 inches per second (in/s).
4. Time held under compression: 10, 30, or 50 seconds.
5. Two replications.

Test 1B (compressive force for 6 compressive cycles):
1. Number of times compressed: 6.
2. Eighteen replications.

Test 2 (resilient force):
1. Number of times compressed: 1 or 6.
2. Density-restrained-at: 25, 30, or 35 lb/ft$^3$.
3. Compression rate: 5.06, 2.70, or 1.80 in/s.
4. Time held under compression: 10, 30, or 50 seconds.
5. Two replications.

The same bales were used in all three tests. In test 1A the cotton was compressed, held under compression for 10, 30, or 50 seconds, released 12 inches and then recompressed. The force-versus-density relationship was monitored continuously for all densities between 8 and 40 lb/ft$^3$. In test 1B the bales from test 1A were immediately recompressed four times, and the maximum force required to attain a maximum density of approximately 40 lb/ft$^3$ was measured. In test 2, the resilient force exerted by the bales after being compressed one or six times was monitored at densities of 25, 30, and 35 lb/ft$^3$. The procedure used was to compress the bale, slowly lower the ram by manually opening a needle valve (thereby allowing the bale density to decrease), and repress the bale five times, allowing the ram to lower slowly after the fifth recompression.

Experiment 2 (constant pressure) was designed as follows:

Test 1 (compressive force):
1. Number of times compressed: 1 to 11.
2. Three replications.

Test 2 (resilient force):
1. Number of times compressed: 1 or 2.
2. Density-restrained-at: 20.0, 24.0, 28.2, 32.0, 36.2, 40.0, 44.1, or 46.8 lb/ft$^3$.
3. Three replications.

In test 1 the bales were compressed, the ram lowered 12 inches (by bleeding the hydraulic pressure with a needle valve), the bales recompressed, and the procedure repeated until the bale had been compressed 11 times with constant maximum pressure. In test 2 the bales were compressed with 1,800 pounds per square inch (lb/in$^2$) of pressure to a platen separation of approximately 5 inches, after which the ram was lowered slowly to a platen separation of 12 inches. The bales were then recompressed with the same pressure, and the force-versus-density relationship was monitored as the ram descended.

Factorial experiments with randomized complete-block designs were used as statistical designs for tests 1A and 2 of experiment 1 and for test 2 of experiment 2. Completely random designs were used for test 1B of experiment 1 and for test 1 of experiment 2.

[3] Anthony, W. S., and McCaskill, O. L. Development and evaluation of a small-scale cotton ginning system. U.S. Dep. Agric., Agric. Res. Serv. [Rep.] ARS-S-36, 9 pp. 1973.

TABLE 1.—*Test variables and compressive force required to repetitively compress lint cotton to constant maximum density*

[Experiment 1 test 1A; average data for 2 replications]

| No. times compressed | Density-pressed-to (lb/ft³) | Compression rate (in/s) | Time held under compression (s) | Moisture content (pct) | Density-previously-pressed-to (lb/ft³) | Foreign-matter content (pct) | Compressive force (lb) |
|---|---|---|---|---|---|---|---|
| 1 | 20 | 5.06 | 10 | 6.21 | 2.77 | 4.09 | 9,181 |
| 1 | 20 | 5.06 | 30 | 5.85 | 2.77 | 4.03 | 9,059 |
| 1 | 20 | 5.06 | 50 | 5.90 | 2.80 | 4.08 | 8,314 |
| 1 | 20 | 2.70 | 10 | 5.87 | 2.80 | 4.17 | 8,744 |
| 1 | 20 | 2.70 | 30 | 5.91 | 2.77 | 3.99 | 8,944 |
| 1 | 20 | 2.70 | 50 | 6.06 | 2.83 | 4.50 | 8,722 |
| 1 | 20 | 1.80 | 10 | 6.00 | 2.80 | 3.96 | 7,963 |
| 1 | 20 | 1.80 | 30 | 5.96 | 2.78 | 4.61 | 8,349 |
| 1 | 20 | 1.80 | 50 | 6.15 | 2.75 | 4.50 | 8,577 |
| 1 | 25 | 5.06 | 10 | 6.21 | 2.77 | 4.09 | 20,228 |
| 1 | 25 | 5.06 | 30 | 5.85 | 2.77 | 4.03 | 19,804 |
| 1 | 25 | 5.06 | 50 | 5.90 | 2.80 | 4.08 | 18,066 |
| 1 | 25 | 2.70 | 10 | 5.87 | 2.80 | 4.17 | 19,317 |
| 1 | 25 | 2.70 | 30 | 5.91 | 2.77 | 3.99 | 19,356 |
| 1 | 25 | 2.70 | 50 | 6.06 | 2.83 | 4.50 | 18,951 |
| 1 | 25 | 1.80 | 10 | 6.00 | 2.80 | 3.96 | 18,013 |
| 1 | 25 | 1.80 | 30 | 5.96 | 2.78 | 4.61 | 18,079 |
| 1 | 25 | 1.80 | 50 | 6.15 | 2.75 | 4.50 | 18,792 |
| 1 | 30 | 5.06 | 10 | 6.21 | 2.77 | 4.09 | 38,387 |
| 1 | 30 | 5.06 | 30 | 5.85 | 2.77 | 4.03 | 37,175 |
| 1 | 30 | 5.06 | 50 | 5.90 | 2.80 | 4.08 | 33,584 |
| 1 | 30 | 2.70 | 10 | 5.87 | 2.80 | 4.17 | 35,602 |
| 1 | 30 | 2.70 | 30 | 5.91 | 2.77 | 3.99 | 36,458 |
| 1 | 30 | 2.70 | 50 | 6.06 | 2.83 | 4.50 | 35,269 |
| 1 | 30 | 1.80 | 10 | 6.00 | 2.80 | 3.96 | 33,495 |
| 1 | 30 | 1.80 | 30 | 5.96 | 2.78 | 4.61 | 33,380 |
| 1 | 30 | 1.80 | 50 | 6.15 | 2.75 | 4.50 | 34,521 |
| 1 | 35 | 5.06 | 10 | 6.21 | 2.77 | 4.09 | 64,303 |
| 1 | 35 | 5.06 | 30 | 5.85 | 2.77 | 4.03 | 62,547 |
| 1 | 35 | 5.06 | 50 | 5.90 | 2.80 | 4.08 | 56,351 |
| 1 | 35 | 2.70 | 10 | 5.87 | 2.80 | 4.17 | 58,225 |
| 1 | 35 | 2.70 | 30 | 5.91 | 2.77 | 3.99 | 58,524 |
| 1 | 35 | 2.70 | 50 | 6.06 | 2.83 | 4.50 | 57,895 |
| 1 | 35 | 1.80 | 10 | 6.00 | 2.80 | 3.96 | 54,998 |
| 1 | 35 | 1.80 | 30 | 5.96 | 2.78 | 4.61 | 55,155 |
| 1 | 35 | 1.80 | 50 | 6.15 | 2.75 | 4.50 | 56,565 |
| 2 | 20 | 5.06 | 10 | 6.21 | 40.10 | 4.09 | 483 |
| 2 | 20 | 5.06 | 30 | 5.85 | 40.10 | 4.03 | 790 |
| 2 | 20 | 5.06 | 50 | 5.90 | 40.50 | 4.08 | 282 |
| 2 | 20 | 2.70 | 10 | 5.87 | 39.39 | 4.17 | 469 |
| 2 | 20 | 2.70 | 30 | 5.91 | 39.30 | 3.99 | 312 |
| 2 | 20 | 2.70 | 50 | 6.06 | 40.17 | 4.50 | 547 |
| 2 | 20 | 1.80 | 10 | 6.00 | 39.79 | 3.96 | 425 |
| 2 | 20 | 1.80 | 30 | 5.96 | 39.49 | 4.61 | 445 |
| 2 | 20 | 1.80 | 50 | 6.15 | 39.10 | 4.50 | 575 |
| 2 | 25 | 5.06 | 10 | 6.21 | 40.10 | 4.09 | 1,433 |
| 2 | 25 | 5.06 | 30 | 5.85 | 40.10 | 4.03 | 1,832 |
| 2 | 25 | 5.06 | 50 | 5.90 | 40.50 | 4.08 | 796 |
| 2 | 25 | 2.70 | 10 | 5.87 | 39.39 | 4.17 | 1,295 |
| 2 | 25 | 2.70 | 30 | 5.91 | 39.30 | 3.99 | 1,114 |

TABLE 1.—*Test variables and compressive force required to repetitively compress lint cotton to constant maximum density*—Continued

[Experiment 1 test 1A; average data for 2 replications]

| No. times compressed | Density-pressed-to (lb/ft³) | Compression rate (in/s) | Time held under compression (s) | Moisture content (pct) | Density-previously-pressed-to (lb/ft³) | Foreign-matter content (pct) | Compressive force (lb) |
|---|---|---|---|---|---|---|---|
| 2 | 25 | 2.70 | 50 | 6.06 | 40.17 | 4.50 | 1,138 |
| 2 | 25 | 1.80 | 10 | 6.00 | 39.79 | 3.96 | 1,229 |
| 2 | 25 | 1.80 | 30 | 5.96 | 39.49 | 4.61 | 1,230 |
| 2 | 25 | 1.80 | 50 | 6.15 | 39.10 | 4.50 | 1,250 |
| 2 | 30 | 5.06 | 10 | 6.21 | 40.10 | 4.09 | 4,116 |
| 2 | 30 | 5.06 | 30 | 5.85 | 40.10 | 4.03 | 6,385 |
| 2 | 30 | 5.06 | 50 | 5.90 | 40.50 | 4.08 | 4,953 |
| 2 | 30 | 2.70 | 10 | 5.87 | 39.39 | 4.17 | 5,937 |
| 2 | 30 | 2.70 | 30 | 5.91 | 39.30 | 3.99 | 5,267 |
| 2 | 30 | 2.70 | 50 | 6.06 | 40.17 | 4.50 | 3,953 |
| 2 | 30 | 1.80 | 10 | 6.00 | 39.79 | 3.96 | 4,012 |
| 2 | 30 | 1.80 | 30 | 5.96 | 39.49 | 4.61 | 5,525 |
| 2 | 30 | 1.80 | 50 | 6.15 | 39.10 | 4.50 | 4,500 |
| 2 | 35 | 5.06 | 10 | 6.21 | 40.10 | 4.09 | 20,886 |
| 2 | 35 | 5.06 | 30 | 5.85 | 40.10 | 4.03 | 27,543 |
| 2 | 35 | 5.06 | 50 | 5.90 | 40.50 | 4.08 | 23,203 |
| 2 | 35 | 2.70 | 10 | 5.87 | 39.39 | 4.17 | 26,089 |
| 2 | 35 | 2.70 | 30 | 5.91 | 39.30 | 3.99 | 25,715 |
| 2 | 35 | 2.70 | 50 | 6.06 | 40.17 | 4.50 | 18,287 |
| 2 | 35 | 1.80 | 10 | 6.00 | 39.79 | 3.96 | 20,107 |
| 2 | 35 | 1.80 | 30 | 5.96 | 39.49 | 4.61 | 24,580 |
| 2 | 35 | 1.80 | 50 | 6.15 | 39.10 | 4.50 | 21,000 |

Five moisture-content lint samples (wet basis) and three foreign-matter lint samples were taken from each replication and evaluated in the Cotton Testing Laboratory in Stoneville, Miss.

# RESULTS AND ANALYSIS

## Constant Density

### Compressive force

The results for experiment 1 test 1A are shown in table 1. The average density-pressed-to was 39.8 lb/ft³, and the average moisture content was 6.0%. Variation in moisture content was corrected by using analysis of covariance (ANCOV). The ANCOV (table 2) indicates that the number of times compressed, density-pressed-to, and their interaction were significant at the 1% level of probability. The covariate lint-moisture content and blocks were significant at the 10% level. The compression rate, time held under compression, and their interactions were not significant at the 10% level.

A stepwise multiple linear regression analysis of the first compression data indicated that the following logarithmical equation yielded the best results:

$$\log F_c = -0.85340 + 3.65718 \log D_p, \quad (1)$$

where $F_c$=compressive force (pounds),
and $D_p$=density-pressed-to (8 to 40 lb/ft³).

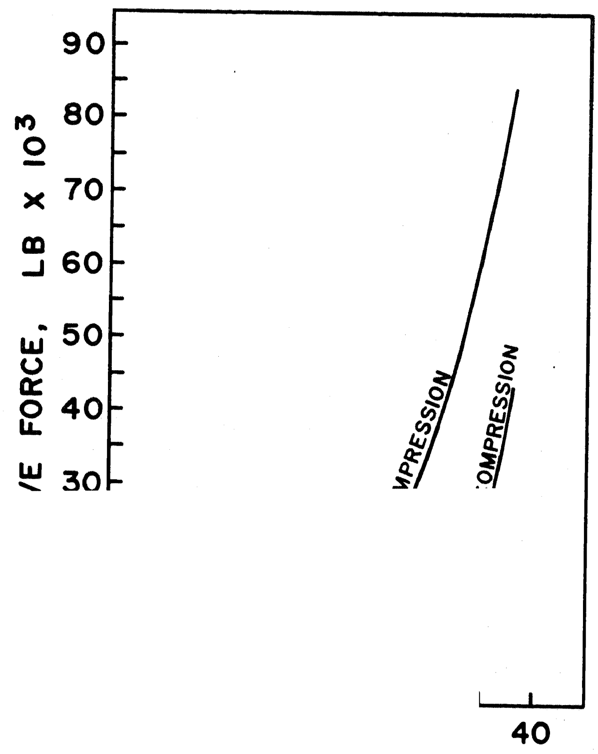
The equation had a coefficient of determination of 0.99. This equation includes data from only the first compression of the bales at 6% lint moisture. The associated analysis of variance for regression indicated a significance level of 1% for $F$. The stepwise addition of compression rate and time held under compression did not significantly increase the coefficient of determination.

A similar stepwise regression analysis was conducted on data from the second compression involving a density range of 15 to 40 lb/ft³, resulting in the equation

$$F_c = -286 + 1.00715\times10^{-8}\, D_p^{\,8}. \quad (2)$$

The coefficient of determination ($R^2$=0.947) for equation 2 was slightly lower than for equation 1, and the optimum equations involved different data transformations. Logarithmic data transformations for the second compression data gave an $R^2$ of 0.86. The analysis of variance indicated a highly significant $F$ value (1% level) for both equations (table 3). The addition of compression rate and time held under compression did not increase the coefficient of determination.

Equations 1 and 2 apply only to 20.16-pound bales packaged at 6% lint moisture in the small-scale press. The inclusion of other variable levels must be done with caution. The response trend would be similar but not exact. A comparison can be made from the force-density curves for the first and second compressions (fig. 2). The force curve for the second compression increases very sharply as the density approaches the density reached in the first compression.




recompress
le press.

TABLE 2.—*Analysis of covariance for randomized complete-block design used to evaluate compressive force*[1]

[Experiment 1 test 1A]

| Source of variation | Degree of freedom | Mean square | $F$ |
|---|---|---|---|
| A | 1 | $1.88 \times 10^9$ | 1,767.41*** |
| B | 3 | $8.19 \times 10^9$ | 854.11*** |
| C | 2 | $1.88 \times 10^7$ | 1.77ns |
| D | 2 | $6.69 \times 10^6$ | .63ns |
| AB | 3 | $1.22 \times 10^{10}$ | 127.30*** |
| AC | 2 | $9.58 \times 10^6$ | .90ns |
| AD | 2 | $5.29 \times 10^6$ | .50ns |
| BC | 6 | $7.36 \times 10^6$ | .69ns |
| BD | 6 | $6.85 \times 10^6$ | .64ns |
| CD | 4 | $1.59 \times 10^7$ | 1.49ns |
| ABC | 6 | $1.62 \times 10^6$ | .15ns |
| ABD | 6 | $3.33 \times 10^6$ | .31ns |
| ACD | 4 | $1.29 \times 10^7$ | 1.21ns |
| BCD | 12 | $1.58 \times 10^6$ | .15ns |
| ABCD | 12 | $4.09 \times 10^6$ | .38ns |
| Blocks | 1 | $4.27 \times 10^7$ | 4.01** |
| Covariate | 1 | $3.46 \times 10^7$ | 3.25* |
| Error | 70 | $1.06 \times 10^7$ | .... |
| Total | 143 | ... ... | .... |

[1] A=number of times compressed. B=density-pressed-to. C=compression rate. D=time held under compression. Covariate=lint-moisture content. ns=not significant at the 10% level. *=significant at the 10% level. **=significant at the 5% level. ***=significant at the 1% level.

TABLE 3.—*Analysis of variance for regression of equations 1 through 6*

| Equation[1] | Source of variation | Degree of freedom | $F$ |
|---|---|---|---|
| 1 | Regression | 1 | *** |
| 1 | Error | 899 | ... |
| 2 | Regression | 1 | *** |
| 2 | Error | 143 | ... |
| 3 | Regression | 2 | *** |
| 3 | Error | 168 | ... |
| 4 | Regression | 2 | *** |
| 4 | Error | 94 | ... |
| 5 | Regression | 3 | *** |
| 5 | Error | 361 | ... |
| 6 | Regression | 3 | *** |
| 6 | Error | 44 | ... |

[1] Equations 3, 4, 5, and 6 follow in text.
***=significant at the 1% level.

### Six compressive cycles

Each of the 18 bales pressed and repressed to determine the effect of one recompression cycle was used to evaluate the effect of additional recompression (experiment 1 test 1B). The bales were repressed four additional times to constant maximum density, and the force required to recompress each bale was measured at the maximum density attained. Compression rates and times held under compression were not used as variables but as replications. Figure 3 demonstrates the effect of compressive cycles on force. A one-way analysis of variance with 18 replications indicated that the compression cycles were significant at the 1% level.

Duncan's new multiple-range test was used to separate the means (table 4). The first compression cycle was significantly different from each of the five subsequent compression cycles, and cycle 2 was different from cycles 5 and 6. No significant difference existed between cycles 2, 3, and 4 or between 3, 4, 5, and 6. Cycles 2, 3, 4, 5, and 6 required 19, 22, 26 and 26% less compressive force, respectively, than cycle 1. From a practical standpoint this means that the second cycle required 19% less force to achieve a density of 39.8 lb/ft³.

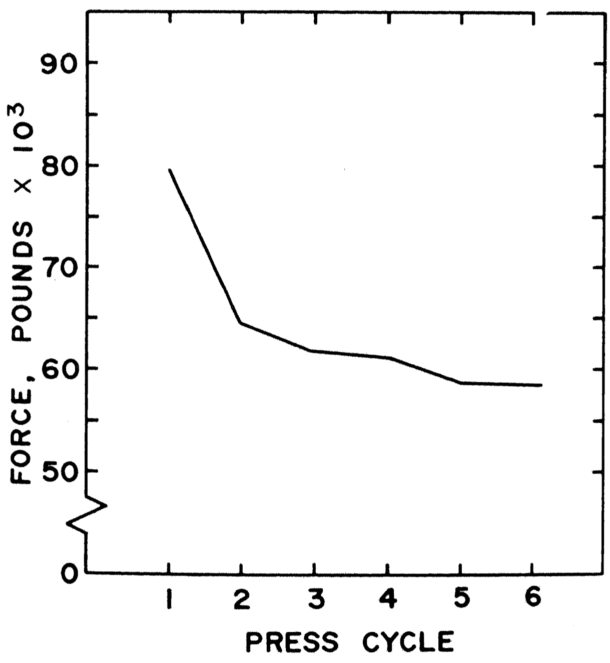



**FIGURE 3.—Effect on force requirements of repetitively compressing approximately 20 pounds of lint to average density of 39.8 lb/ft³.**

In summary, repetitive compression of lint cotton to constant maximum density decreases the force required to attain densities equal to or less than the maximum density obtained on previous compressive cycles. The largest force decrease occurs between the first and second cycles. The force difference between successive cycles decreases as the number of cycles increases.

### Resilient force

The objective of experiment 1 test 2 was to investigate the effect of compression rate, density-restrained-at, time held under compression, and repetitive compression on resilient force. Resilient force is the force exerted by the cotton as it is restrained. The instrumentation used in the compression-force experiment was also used in this study. A randomized complete-block design in a factorial arrangement with four factors and two replications was used.

The lint cotton was compressed six consecutive times to an average density of 39.8 lb/ft³. The average lint moisture was 6.0%. The resilient force was recorded after the first compression cycle and again after the sixth compression cycle. The ram moved downward slowly, and the force transmitted through the cotton was monitored as the density gradually decreased.

The resilient force varied from 530 to 7,432 pounds as the treatments were applied (table 5). The density-pressed-to varied from 39.1 to 40.5 lb/ft³, and lint moisture varied from 5.85

TABLE 4.—*Separation of means for six compression cycles with Duncan's new multiple-range test*

[Experiment 1 test 1B]

| Compression cycle | Mean force (lb) | Significance[1] |
|---|---|---|
| 1 | 79,767 | a |
| 2 | 64,556 | b |
| 3 | 61,984 | bc |
| 4 | 61,164 | bc |
| 5 | 58,953 | c |
| 6 | 58,718 | c |

[1] Any 2 means not followed by the same letter are significantly different at the 1% level.

TABLE 5.—*Test variables and resilient force exerted by lint cotton compressed to constant maximum density in small-scale bale press*

[Experiment 1 test 2; average data for 2 replications]

| No. times compressed | Density-restrained-at (lb/ft³) | Compression rate (in/s) | Time held under compression (s) | Density-pressed-to (lb/ft³) | Moisture content (pct) | Foreign-matter content (pct) | Resilient force (lb) |
|---|---|---|---|---|---|---|---|
| 1 | 25 | 5.06 | 10 | 40.1 | 6.21 | 4.09 | 1,328 |
| 1 | 25 | 5.06 | 30 | 40.1 | 5.85 | 4.03 | 1,484 |
| 1 | 25 | 5.06 | 50 | 40.5 | 5.90 | 4.08 | 860 |
| 1 | 25 | 2.70 | 10 | 39.4 | 5.87 | 4.17 | 750 |
| 1 | 25 | 2.70 | 30 | 39.3 | 5.91 | 3.99 | 1,381 |
| 1 | 25 | 2.70 | 50 | 40.2 | 6.06 | 4.50 | 818 |
| 1 | 25 | 1.80 | 10 | 39.8 | 6.00 | 3.96 | 834 |
| 1 | 25 | 1.80 | 30 | 39.5 | 5.96 | 4.61 | 1,127 |
| 1 | 25 | 1.80 | 50 | 39.1 | 6.15 | 4.50 | 1,239 |
| 1 | 30 | 5.06 | 10 | 40.1 | 6.21 | 4.09 | 2,240 |
| 1 | 30 | 5.06 | 30 | 40.1 | 5.85 | 4.03 | 2,188 |
| 1 | 30 | 5.06 | 50 | 40.5 | 5.90 | 4.08 | 1,596 |
| 1 | 30 | 2.70 | 10 | 39.4 | 5.87 | 4.17 | 1,616 |
| 1 | 30 | 2.70 | 30 | 39.3 | 5.91 | 3.99 | 2,083 |
| 1 | 30 | 2.70 | 50 | 40.2 | 6.06 | 4.50 | 1,700 |
| 1 | 30 | 1.80 | 10 | 39.8 | 6.00 | 3.96 | 2,012 |
| 1 | 30 | 1.80 | 30 | 39.5 | 5.96 | 4.61 | 2,138 |
| 1 | 30 | 1.80 | 50 | 39.1 | 6.15 | 4.50 | 2,056 |
| 1 | 35 | 5.06 | 10 | 40.1 | 6.21 | 4.09 | 5,793 |
| 1 | 35 | 5.06 | 30 | 40.1 | 5.85 | 4.03 | 5,398 |
| 1 | 35 | 5.06 | 50 | 40.5 | 5.90 | 4.08 | 4,923 |
| 1 | 35 | 2.70 | 10 | 39.4 | 5.87 | 4.17 | 6,143 |
| 1 | 35 | 2.70 | 30 | 39.3 | 5.91 | 3.99 | 7,432 |
| 1 | 35 | 2.70 | 50 | 40.2 | 6.06 | 4.50 | 4,566 |
| 1 | 35 | 1.80 | 10 | 39.8 | 6.00 | 3.96 | 6,734 |
| 1 | 35 | 1.80 | 30 | 39.5 | 5.96 | 4.61 | 6,874 |
| 1 | 35 | 1.80 | 50 | 39.1 | 6.15 | 4.50 | 7,219 |
| 6 | 25 | 5.06 | 10 | 40.1 | 6.21 | 4.09 | 925 |
| 6 | 25 | 5.06 | 30 | 40.1 | 5.85 | 4.03 | 580 |
| 6 | 25 | 5.06 | 50 | 40.5 | 5.90 | 4.08 | 530 |
| 6 | 25 | 2.70 | 10 | 39.4 | 5.87 | 4.17 | 1,002 |
| 6 | 25 | 2.70 | 30 | 39.3 | 5.91 | 3.99 | 891 |
| 6 | 25 | 2.70 | 50 | 40.2 | 6.06 | 4.50 | 869 |
| 6 | 25 | 1.80 | 10 | 39.8 | 6.00 | 3.96 | 1,344 |
| 6 | 25 | 1.80 | 30 | 39.5 | 5.96 | 4.61 | 935 |
| 6 | 25 | 1.80 | 50 | 39.1 | 6.15 | 4.50 | 1,130 |
| 6 | 30 | 5.06 | 10 | 40.1 | 6.21 | 4.09 | 1,846 |
| 6 | 30 | 5.06 | 30 | 40.1 | 5.85 | 4.03 | 1,766 |
| 6 | 30 | 5.06 | 50 | 40.5 | 5.90 | 4.08 | 1,225 |
| 6 | 30 | 2.70 | 10 | 39.4 | 5.87 | 4.17 | 1,250 |
| 6 | 30 | 2.70 | 30 | 39.3 | 5.91 | 3.99 | 2,424 |
| 6 | 30 | 2.70 | 50 | 40.2 | 6.06 | 4.50 | 1,797 |
| 6 | 30 | 1.80 | 10 | 39.8 | 6.00 | 3.96 | 1,856 |
| 6 | 30 | 1.80 | 30 | 39.5 | 5.96 | 4.61 | 1,149 |
| 6 | 30 | 1.80 | 50 | 39.1 | 6.15 | 4.50 | 1,611 |
| 6 | 35 | 5.06 | 10 | 40.1 | 6.21 | 4.09 | 5,815 |
| 6 | 35 | 5.06 | 30 | 40.1 | 5.85 | 4.03 | 4,595 |
| 6 | 35 | 5.06 | 50 | 40.5 | 5.90 | 4.08 | 3,790 |
| 6 | 35 | 2.70 | 10 | 39.4 | 5.87 | 4.17 | 4,199 |
| 6 | 35 | 2.70 | 30 | 39.3 | 5.91 | 3.99 | 5,884 |

TABLE 5.—*Test variables and resilient force exerted by lint cotton compressed to constant maximum density in small-scale bale press*—Continued

[Experiment 1 test 2; average data for 2 replications]

| No. times compressed | Density-restrained-at (lb/ft³) | Compression rate (in/s) | Time held under compression (s) | Density-pressed-to (lb/ft³) | Moisture content (pct) | Foreign-matter content (pct) | Resilient force (lb) |
|---|---|---|---|---|---|---|---|
| 6 | 35 | 2.70 | 50 | 40.2 | 6.06 | 4.50 | 4,881 |
| 6 | 35 | 1.80 | 10 | 39.8 | 6.00 | 3.96 | 5,458 |
| 6 | 35 | 1.80 | 30 | 39.5 | 5.96 | 4.61 | 5,324 |
| 6 | 35 | 1.80 | 50 | 39.1 | 6.15 | 4.50 | 5,431 |

to 6.21%. The density-pressed-to and lint moisture were considered as covariates. An ANCOV indicated that the density-pressed-to was significant at the 1% level while lint moisture was not significant at the 10% level (table 6). The number of times compressed and the density-restrained-at were significant at the 1% level. Their interaction was significant at the 10% level. Compression rate, time held under compression, and their interaction were not significant at the 10% level. The average resilient force (adjusted for covariance) after the first compression cycle, over all levels of density-restrained-at, compression rate, and time held under compression, was 3,057 pounds. The corresponding value after the sixth compressive cycle was 2,537 pounds. The resilient force decreased 17% as the compression cycles increased from 1 to 6. A comparison of the resilient force after the first and sixth compressions can be made from figure 4. Table 7 illustrates the quantitative differences for the

TABLE 6.—*Analysis of covariance for randomized complete-block design used to investigate resilient force of lint cotton repetitively compressed to constant density in a small-scale bale press*[1]

[Experiment 1 test 2]

| Source of variation | Degree of freedom | Mean square | *F* |
|---|---|---|---|
| Blocks | 1 | $1.04\times10^{6}$ | 1.31ns |
| A | 1 | $7.23\times10^{6}$ | 9.19*** |
| B | 2 | $2.15\times10^{8}$ | 271.26*** |
| C | 2 | $5.90\times10^{5}$ | .75ns |
| D | 2 | $3.90\times10^{5}$ | .50ns |
| AB | 2 | $2.14\times10^{6}$ | 2.70* |
| AC | 2 | $2.04\times10^{5}$ | .26ns |
| AD | 2 | $2.95\times10^{5}$ | .37ns |
| BC | 4 | $1.13\times10^{6}$ | 1.43ns |
| BD | 4 | $3.55\times10^{5}$ | .45ns |
| CD | 4 | $1.49\times10^{6}$ | 1.88ns |
| ABC | 4 | $4.85\times10^{5}$ | .61ns |
| ABD | 4 | $8.79\times10^{4}$ | .11ns |
| ACD | 4 | $3.97\times10^{5}$ | .50ns |
| BCD | 8 | $4.44\times10^{5}$ | .56ns |
| ABCD | 8 | $3.27\times10^{5}$ | .41ns |
| Covariate | 1 | $1.44\times10^{7}$ | 18.16*** |
| Error | 52 | | |
| Total | 107 | ... ... | .... |

[1] A=number of times compressed. B=density-restrained-at. C=compression rate. D=time held under compression. Covariate=density-pressed-to. ns=not significant at the 10% level. *=significant at the 10% level. ***=significant at the 1% level.

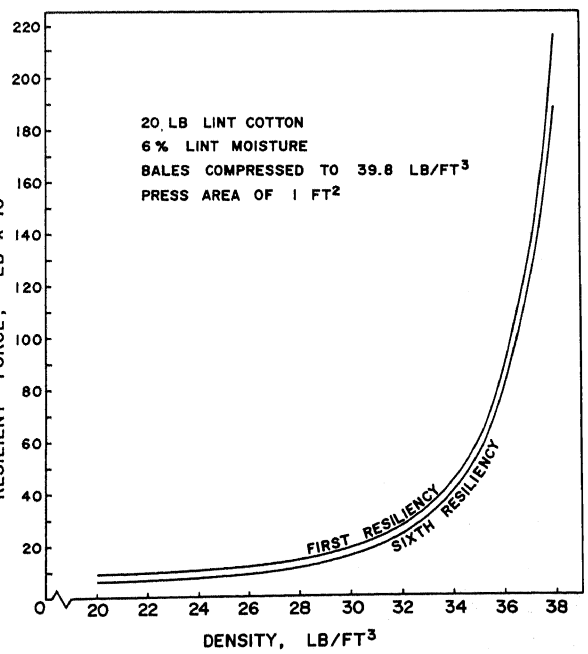



FIGURE 4.—Resilient force after first and sixth compressive cycles to a constant maximum density.

significant interactions (compression cycles times density-restrained-at).

A multiple linear regression analysis was performed separately for the resilient force after the first and sixth compressions. The results were as follows:

First resiliency:

$$\log F_R = 17.9174 - 9.36878 \log D_p + 4.6638 \times 10^{-10} D_R^{6}, \quad (R^2 = 0.96) \tag{3}$$

Sixth resiliency:

$$\log F_R = 18.9169 - 10.1214 \log D_p + 1.9572 \times 10^{-8} D_R^{5}, \quad (R^2 = 0.96) \tag{4}$$

Combined equation:

$$\log F_R = 18.6813 - 0.0134T - 9.8339 \log D_p + 4.6328 \times 10^{-10} D_R^{6}, \quad (R^2 = 0.96) \tag{5}$$

where $F_R$=resilient force (pounds),
$D_R$=density-restrained-at (pounds per cubic foot),
$D_p$=final density-pressed-to (pounds per cubic foot),
and $T$=number of times compressed (1 or 6).

The coefficient of determination (0.96) for the combined equation (5) indicates that the curve fit is reasonably good. The analysis of variance for regression indicated a highly significant (1% level) $F$ value for equations 3, 4, and 5 (table 3). An evaluation of equation 5 at one and six compression cycles, where $D_p$= 39.8 lb/ft³ and $D_R$=28.0 lb/ft³, indicated a 14% reduction in resilient force as the cycles increased from one to six.

In summary, repetitive compression of the lint cotton reduces the resilient force exerted by the cotton. Compression rate and time held under compression do not significantly affect resilient force.

## Constant Pressure

### Compressive force

The analysis of variance indicated that the compression cycles were significant at the 5% level. The maximum density attained by repetitively compressing lint cotton 11 times with 1,800 lb/in² of constant hydraulic pressure increased as the compression cycles increased.

TABLE 7.—*Means of quantitative differences for significant interactions*[1]

[Experiment 1 test 2]

| Interaction[2] | Mean resilient force (lb) | Difference (pct) |
|---|---|---|
| A1B1C.D. | 1,091 | −16 |
| A2B1C.D. | 912 | |
| A1B2C.D. | 1,958 | −15 |
| A2B2C.D. | 1,658 | |
| A1B3C.D. | 6,120 | −18 |
| A2B3C.D. | 5,042 | |

[1] Compression cycles times density-restrained-at.
[2] The interaction codes (A, B, C, and D) are specified in Table 6.

TABLE 8.—*Separation of means for 11 compression cycles with Duncan's new multiple-range test*

[Experiment 2 test 1]

| Compression cycle | Mean maximum density (lb/ft³) | Significance[1] |
|---|---|---|
| 1 | 47.5 | a |
| 2 | 48.6 | b |
| 3 | 48.9 | bc |
| 4 | 49.2 | bcd |
| 5 | 49.7 | cd |
| 6 | 49.8 | cd |
| 7 | 50.0 | d |
| 8 | 50.2 | e |
| 9 | 50.4 | e |
| 10 | 50.4 | e |
| 11 | 50.6 | e |

[1] Any 2 means not followed by the same letter are significantly different at the 1% level.

The treatment means were analyzed by Duncan's new multiple-range test; the results are given in table 8. The density obtained on the first cycle was significantly different from the 10 subsequent press cycles. Cycle 2 was significantly different from cycles 5 through 11.

Figure 5 demonstrates the logarithmic change in density as the number of compression cycles increased. The second press cycle increased the density by 2.32% (47.5 to 48.6 lb/ft³). The change in density is small; however, from extrapolating equation 1, 8.73% more force is required to reach a density of 48.6 lb/ft³, as compared to 47.5 lb/ft³.

Repetitive compression can be beneficial in constant-density systems when the proper platen separation (density) for automatic bale tying cannot be attained with the available hydraulic pressure. Recompressing the bale will decrease the platen separation (thereby increasing the density) until the automatic tying system is able to function. In the small-scale press with 20 pounds of cotton; a change in platen separation of approximately one-eighth inch is required for a density change from 47.5 to 48.6 lb/ft$^3$. In a full-scale (7.5 ft$^2$) system, a change of approximately three-eighths inch in platen separation is required for the same density change for a 500-pound bale.

**Resilient force**

In experiment 2 test 2, three bales were compressed with 1,800 lb/in$^2$ of hydraulic pressure and gradually released. Three other bales were compressed and recompressed with 1,800 lb/in$^2$ of pressure and gradually released. The relationship of resilient force and density was monitored as the bales were released. The effect of one and two compression cycles on the resilient force is shown in table 9. The importance of repetitive compression is shown in figure 6.

Regression analysis of the data yielded the equation

$$\log F_R = -55.9421 - 0.4765T + 35.22 \log D_p + 1.975\times 10^{-10} D_R^6. \quad (6)$$

The coefficient of determination (0.97) indicates that 97% of the sums of squares was due to the independent variables. The resilient force at $D_R$=28.2 lb/ft$^3$ was reduced 25% by the second compressive cycle (equation 6).

TABLE 9.—*Test variables and resilient force exerted by 20 pounds of lint cotton compressed and recompressed to 1,800 lb/in² in small-scale bale press*

[Experiment 2 test 2; average data for 3 replications]

| Times compressed | Density-restrained-at (lb/ft$^3$) | Density-pressed-to (lb/ft$^3$) | Moisture content (pct) | Resilient force (lb) |
|---|---|---|---|---|
| 1 | 46.8 | 47.5 | 10.8 | 42,770 |
| 1 | 44.1 | 47.5 | 10.8 | 10,885 |
| 1 | 40.0 | 47.5 | 10.8 | 3,824 |
| 1 | 36.2 | 47.5 | 10.8 | 1,689 |
| 1 | 32.0 | 47.5 | 10.8 | 924 |
| 1 | 28.2 | 47.5 | 10.8 | 605 |
| 1 | 24.0 | 47.5 | 10.8 | 388 |
| 1 | 20.0 | 47.5 | 10.8 | 261 |
| 2 | 46.8 | 48.6 | 10.3 | 23,077 |
| 2 | 44.1 | 48.6 | 10.3 | 7,187 |
| 2 | 40.0 | 48.6 | 10.3 | 2,735 |
| 2 | 36.2 | 48.6 | 10.3 | 1,347 |
| 2 | 32.0 | 48.6 | 10.3 | 702 |
| 2 | 28.2 | 48.6 | 10.3 | 434 |
| 2 | 24.0 | 48.6 | 10.3 | 285 |
| 2 | 20.0 | 48.6 | 10.3 | 188 |

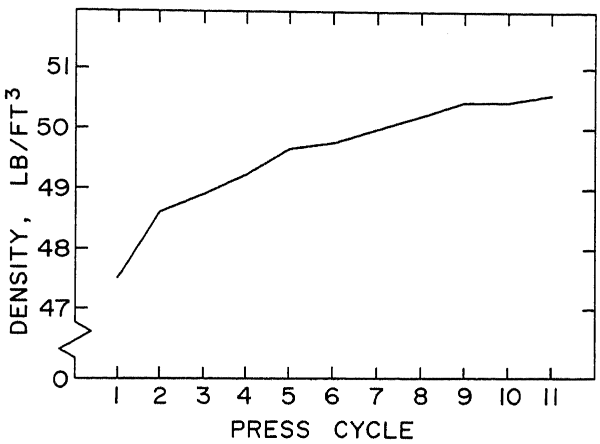



FIGURE 5.—Effect on density of repetitively compressing 20 pounds of lint cotton with constant pressure of 1,800 lb/in$^2$.

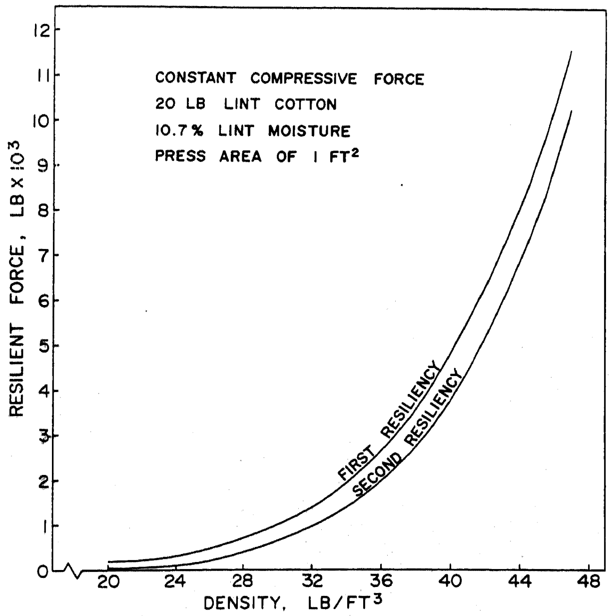



FIGURE 6.—Resilient force after first and second compressive cycles at constant pressure of 1,800 lb/in$^2$.

However, direct comparison of the results of one and two repetitive compressive cycles is not possible, since the difference attributable to $D_p$ is inherently included. Resilient forces were not measured after one and two compressive cycles for each bale but were measured on different bales. $D_p$ increased from 47.5 to 48.6 lb/ft$^3$ as the compressive cycles increased from one to two.

## CONCLUSIONS

The force required to compress lint cotton is not significantly influenced by compression rate or time held under compression. Repetitive compression of lint cotton to constant densities requires less compressive force as the number of compression cycles increases. The largest decrease occurs between the first and second compression cycles. The resilient forces exerted by lint cotton decrease as the number of compression cycles increases. The practical importance of the above is that the force exerted on bale ties can be significantly reduced by repetitive compression. The energy required to press and repress the bale will be greater than that required to press the bale initially. That additional cost must be justified economically before repetitive compression can be feasible. A definite advantage would exist if a press system were producing bales with excessive tie breakage caused by resilient force. The tie breakage could be reduced by repetitive compression. The additional energy cost for repetitive compression would be small compared to the possible decrease in bale value from tie breakage or the cost of repackaging the bale.

Repetitively compressing lint cotton with constant pressure increases the final density that the bale is pressed to. The largest increase in density occurs between the first and second press cycles. Repetitive compression with constant pressure also reduces the resilient force exerted by lint cotton. The decrease in resilient force, as the number of compression cycles with constant pressure increases, is attributable to the cyclic effect and to the increase in the final density-pressed-to. The practical importance of repetitive compression with constant pressure lies in the reduction of bale-tie breakage as well as in providing a means to allow the platen separation to decrease to the predetermined distance necessary for automatic tying.

* 1977-GPO-1750-S/771-040/17

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